

Healthcare Engineering Defined: A White Paper

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ABSTRACT

Engineering has been playing an important role in serving and advancing healthcare. The term "Healthcare Engineering" has been used by professional societies, universities, scientific authors, and the healthcare industry for decades. However, the definition of "Healthcare Engineering" remains ambiguous. The purpose of this position paper is to present a definition of Healthcare Engineering as an academic discipline, an area of research, a field of specialty, and a profession. Healthcare Engineering is defined in terms of what it is, who performs it, where it is performed, and how it is performed, including its purpose, scope, topics, synergy, education/training, contributions, and prospects.

Keywords: Healthcare engineering, definition, purpose, scope, topics, synergy, jobs, education, training, contributions, future

1. PREAMBLE

Engineering has been playing a crucial role in serving healthcare, bringing about revolutionary advances in healthcare. Contributions have been made by engineers from almost all engineering disciplines, such as Biomedical, Chemical, Civil, Computer, Electrical, Environmental, Industrial, Information, Materials, Mechanical, Software, and Systems Engineering, as well as healthcare professionals such as physicians, dentists, nurses, pharmacists, allied health professionals, and health scientists who are engaged in supporting, improving, and/or advancing any aspect of healthcare through engineering approaches. "Healthcare Engineering" is the most appropriate term to encompass such a multi-disciplinary specialty, considering that advancing healthcare is the common goal for all such efforts made through engineering approaches. However, so far, a clear, rigorous definition of "Healthcare Engineering" has never been documented.

Established over 50 years ago, the American Society of Healthcare Engineering (ASHE) [1] was one of the first to publicize the term "Healthcare Engineering". ASHE, as well as its many local affiliate societies (e.g., [2]), has been mainly dedicated to the health care physical environment, which represents only one sector of what engineers do in healthcare. David and Goodman [3] first used the term "healthcare engineers" in the scientific literature in 1989, where the critical role of the engineer in the healthcare delivery system was discussed. A number of academic programs have adopted the term "Healthcare Engineering" in their names (e.g., [4–13]). However, the description/definition of "Healthcare Engineering" by these programs varies, as each

institution has designed its program based on its own distinctive interest, strength, focus, and emphasis, and hence created a different description/definition accordingly. Each of these versions of description/definition excellently portrays a certain facet of Healthcare Engineering, though none reflects all dimensions of the discipline. Further, the *Journal of Healthcare Engineering* [14], launched in 2010, focuses on engineering involved in all aspects of healthcare delivery processes and systems. “Healthcare Engineering” has also appeared in the commercial names of healthcare companies with various foci.

The purpose of this document is to present a clear, rigorous definition of Healthcare Engineering as an academic discipline, an area of research, a field of specialty, and a profession, as well as its prospects. The co-authors are all active members and contributors to the Healthcare Engineering community from different parts of the world. This document is based on our knowledge and experience accumulated through years of serving and promoting Healthcare Engineering.

2. HEALTHCARE ENGINEERING DEFINED

Healthcare Engineering is defined in this section in terms of what it is, who performs it, where it is performed, and how it is performed.

2.1. What

2.1.1. Definition

In the short and straightforward version, “Healthcare Engineering” can be defined as follows:

Healthcare Engineering is engineering involved in all aspects of healthcare.

The term “engineering” covers all engineering disciplines such as Biomedical, Chemical, Civil, Computer, Electrical, Environmental, Industrial, Information, Materials, Mechanical, Software, and Systems Engineering.

A more elaborated definition can be developed based on “healthcare” defined as:

- “The maintenance and improvement of physical and mental health, especially through the provision of medical services” [15].
- “The prevention, treatment, and management of illness and the preservation of mental and physical well-being through the services offered by the medical and allied health professions.” [16].

Therefore, a more detailed definition of Healthcare Engineering is the following:

Healthcare Engineering is engineering involved in all aspects of the prevention, diagnosis, treatment, and management of illness, as well as the preservation and improvement of physical and mental health and well-being, through the services offered to humans by the medical and allied health professions.

2.1.2. Purpose

The purpose of Healthcare Engineering is to improve human health and well-being through engineering approaches.

2.1.3. Scope

Healthcare Engineering covers the following two major areas:

(I) Engineering for Healthcare Intervention

The U.S. Department of Health & Human Services (USDHHS) [17] defines “healthcare intervention” as “*Any type of treatment, preventive care, or test that a person could take or undergo to improve health or to help with a particular problem*”. USDHHS further specifies that healthcare interventions include drugs, foods, supplements, vaccinations, screening tests, exercises, hospital treatment, and certain kinds of care (such as physical therapy).

(II) Engineering for Healthcare Systems

“Healthcare system” is defined as:

- “*The complete network of agencies, facilities, and all providers of health care in a specified geographic area*” [18].
- “*Complex of facilities, organizations, and trained personnel engaged in providing health care within a geographical area.*” [19].

According to the World Health Organization (WHO) [20], a good health system requires “*a robust financing mechanism; a well-trained and adequately paid workforce; reliable information on which to base decisions and policies; well maintained facilities and logistics to deliver quality medicines and technologies.*”

Therefore, the scope of Healthcare Engineering can be stated as the following:

“Healthcare Engineering covers the following two major fields:

- I. *Engineering for Healthcare Intervention:* Engineering involved in the development or provision of any treatment, preventive care, or test that a person could take or undergo to improve health or to help with a particular health problem.
- II. *Engineering for Healthcare Systems:* Engineering involved in the complete network of organizations, agencies, facilities, information systems, management systems, financing mechanisms, logistics, and all trained personnel engaged in delivering healthcare within a geographical area.”

2.1.4. Subjects

Based on the scope delineated above, the major subjects of Healthcare Engineering are listed in Table 1. Each subject may have its own ramification system covering a number of topics. For instance, within Biomechanics, there are Micro-biomechanics and Macro-biomechanics. Micro-biomechanics further consists of Nano-biomechanics, Molecular Biomechanics, Cellular Biomechanics, and Tissue Biomechanics, with each of them covering a number of topics or even further ramifications. It is unnecessary and impractical for Table 1 to include all those subfields and topics for each subject. As technology progresses, new topics will emerge, while some old topics may become obsolete or be subsumed under others in the future. If we list Healthcare Engineering topics in Table 1, there is no mechanism available for us to update them once this white paper is published in an archival journal. We recommend lists of topics provided and continually updated by authoritative sources such as those leading societies/associations of individual subjects and government organizations.

Table 1. Healthcare Engineering subjects

(I) Engineering for Healthcare Intervention	3. Cardiology
A. Fundamentals	4. Critical Care Medicine
1. Biomechanics	5. Emergency Medicine
2. Biomaterials	6. Endocrinology
3. Biomedical Instruments	7. Gastroenterology
4. Medical Devices	8. General Surgery
5. Engineering for Surgery	9. Geriatrics
6. Medical Imaging	10. Infectious Disease
7. Organ Transplantation	11. Neurology
8. Artificial Organs	12. Neurosurgery
9. Drug Delivery	13. Nuclear Medicine
10. Genetic Engineering	14. Occupational Medicine
11. Engineering for	15. Oncology
Diagnosis/Detection	16. Ophthalmology
12. Health Informatics, Information Engineering & Decision Support	17. Orthopedics
13. Disinfection Engineering	18. Pathology
B. Engineering for Disease Prevention, Diagnosis, Treatment, and Management	19. Pediatrics
1. Cardiovascular Disease	20. Physical Medicine and Rehabilitation
2. Cancer	21. Plastic, Reconstructive and Aesthetic Surgery
3. Alzheimer's Disease	22. Public Health
4. Diabetes	23. Pulmonology
5. Respiratory Disease	24. Radiology
6. Obesity	25. Radiotherapy
7. Degenerative Diseases	26. Rheumatology
8. Others	27. Sports Medicine
C. Engineering for Patient Care	28. Urology
1. Patient Safety	29. Vascular Medicine
2. Critical Care	E. Engineering for Dental Specialties
3. Neonatal Care	1. Endodontics
4. Home Healthcare	2. Oral and Maxillofacial Pathology, Radiology, and Surgery
5. Elderly Care	3. Orthodontics and Dentofacial Orthopedics
6. Patient Monitoring	4. Periodontics
7. Health Disparities	5. Prosthodontics
8. Disaster Management	6. Others
D. Engineering for Medical Specialties	F. Engineering for Allied Health Specialties
1. Allergy and Immunology	1. Audiology
2. Anesthesiology	2. Clinical Laboratory Science
	3. Environmental Health

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| <ul style="list-style-type: none"> 4. Occupational Therapy 5. Orthotics and prosthetics 6. Physical Therapy 7. Rehabilitation 8. Respiratory Therapy 9. Speech Therapy 10. Others | <ul style="list-style-type: none"> 3. Lean, Six Sigma, Total Quality Management 4. Human Factors 5. High Reliability Organization 6. Resilience Engineering 7. Rural Health |
| <ul style="list-style-type: none"> G. Engineering for Nursing - including nursing in all related areas, particularly (I)B, C, D, E, (II)A, and B. | <ul style="list-style-type: none"> B. Healthcare Information Systems |
| <ul style="list-style-type: none"> H. Engineering for Pharmacy | <ul style="list-style-type: none"> 1. Electronic Health Record 2. E-Health 3. M-Health 4. Telemedicine 5. Wireless Technology 6. Data Mining & Big Data 7. Information Security |
| <ul style="list-style-type: none"> 1. Pharmaceutical Design & Development 2. Bio-/Pharmaceutical Manufacturing 3. Pharmaceutical Devices 4. Pharmaceutical Testing 5. Pharmaceutical Information Systems 6. Clinical Science 7. Regulatory Compliance | <ul style="list-style-type: none"> C. Healthcare Facilities |
| <ul style="list-style-type: none"> (II) Engineering for Healthcare Systems | <ul style="list-style-type: none"> 1. Healthcare Infrastructure 2. Healthcare Energy Systems 3. Healthcare Sustainability & Green Design 4. Environmental Health and Safety |
| <ul style="list-style-type: none"> A. Healthcare System Management, Improvement & Reform | <ul style="list-style-type: none"> D. Healthcare Policy |
| <ul style="list-style-type: none"> 1. Quality, Cost, Efficiency, Effectiveness 2. Operations Research & Systems Engineering | <ul style="list-style-type: none"> (III) Others |
| <ul style="list-style-type: none"> A. Healthcare Engineering Education & Training | <ul style="list-style-type: none"> 1. Collegiate Education 2. Continued Education |
| <ul style="list-style-type: none"> B. Future of Healthcare | |

2.1.5. Synergy

Healthcare Engineering includes the healthcare/medical sectors of all engineering disciplines, with an emphasis on the synergy of all these sectors and the engineering/technology sectors of the Health Sciences (medicine, dentistry, allied health, nursing, pharmacy, public health, etc.), as depicted in Figure 1.

2.2. Who

2.2.1. Definition

Healthcare Engineering professionals are mainly (a) engineers from all engineering disciplines such as Biomedical, Chemical, Civil, Computer, Electrical, Environmental, Industrial, Information, Materials, Mechanical, Software, and Systems Engineering, and (b) healthcare professionals such as physicians, dentists, nurses, pharmacists, allied health professionals, and health scientists, who are engaged in supporting, improving, and/or advancing any aspect of healthcare through engineering approaches, in accordance with the above definition of Healthcare Engineering. Since some healthcare professionals engaged in Healthcare Engineering may not be considered to be “engineers”, “Healthcare Engineering professional” is a more appropriate term than “Healthcare Engineer”.

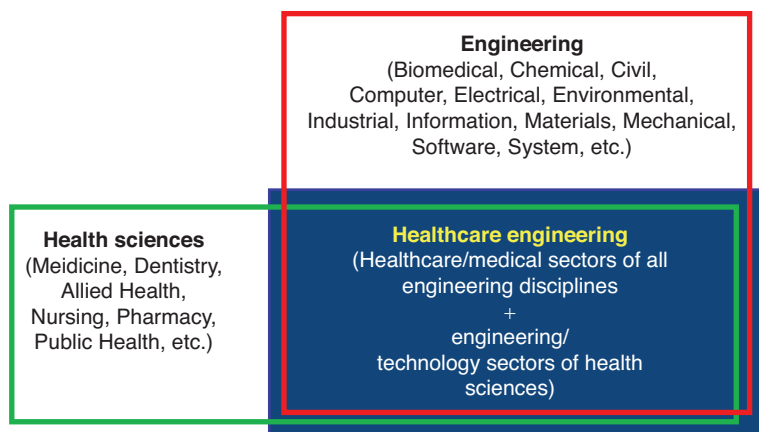


Figure 1. Healthcare Engineering: synergy of engineering and health sciences. Red block: All engineering disciplines. Green block: All health sciences disciplines. Blue block: All Healthcare Engineering disciplines.

2.2.2. Education & Training

Engineers from various engineering disciplines are always in demand in healthcare, as the engineering issues in healthcare require the expertise of specific engineering disciplines. It is a common misconception that only engineers with a background in Biomedical Engineering, Clinical Engineering, or related areas may work in healthcare. However, a major issue is that most existing engineering curricula (particularly undergraduate ones) do not cover sufficient healthcare content, except those in the bio-related areas. There is a need for courses that can fill the gap and better prepare non-biomedical engineering students for service in healthcare. There is also a need for certificate programs that can help practicing engineers transition from other sectors of industry to healthcare which is one of the world's largest and fastest-growing industries. On the other hand, healthcare professionals (physicians, dentists, nurses, pharmacists, allied health professionals, etc.) need to be better trained to apply engineering to their practice, problem solving, and advancing healthcare. Due to the rapid advance of technology, continuing education plays a crucial role in keeping Healthcare Engineering professionals abreast of such advancement and ensuring their continued competence, be they trend followers or innovation leaders. Additionally, since the nature of Healthcare Engineering often requires inter-disciplinary or even inter-professional collaboration among varied disciplines of both healthcare and engineering, there is a need for learning opportunities that develop students' key competencies for working with Healthcare Engineering professionals in the real world, such as through joint projects between universities and hospitals.

2.3. Where

Healthcare Engineering activities generally take place within or surrounding the **healthcare industry**. In other words, the purpose of Healthcare Engineering is achieved by professionals working in/with/for the healthcare industry. A description of the healthcare industry affords a better understanding of the types of Healthcare Engineering jobs, the roles played by Healthcare Engineering professionals, the importance of Healthcare Engineering, and Healthcare Engineering professionals' contributions to society. Although individuals working on Healthcare Engineering in universities, research institutions, government agencies, and other non-industrial organizations may not be working within the healthcare industry *per se*, they typically collaborate with or work for some sectors of the healthcare industry, or make results of their works available through publications for the healthcare industry's adoption, in order for their work to benefit human health.

The healthcare industry is one of the world's largest and fastest-growing industries, and could even be the largest industry in the world [21], and the fastest-growing industry in the US [22]. Healthcare industry is defined as [23]:

"The complex of preventive, remedial, and therapeutic services provided by hospitals and other institutions, nurses, doctors, dentists, medical administrators, government agencies, voluntary agencies, noninstitutional care facilities, pharmaceutical and medical equipment manufacturers, and health insurance companies."

Based on the framework of the Industry Classification Benchmark (ICB) [24], a definitive system categorizing over 70,000 companies and 75,000 securities worldwide and one of the most widely adopted such standards in the business community, major sectors and subsectors of healthcare industry are presented in Table 2. The original ICB classification is changed as we deem appropriate; for instance, a sector of healthcare consulting, support, and education, and a subsector of healthcare systems have been created.

2.4. How

Healthcare Engineering professionals perform their jobs in/with/for the healthcare industry. Their contributions to various sectors and subsectors of the healthcare industry are summarized in Table 2.

3. PROSPECTS

The healthcare industry is expected to remain to be one of the world's largest and fastest-growing industries, and the demand for Healthcare Engineering professionals will continue to grow accordingly. As healthcare changes rapidly and becomes increasingly complex under technological, economic, social, and regulatory impacts, it is anticipated that Healthcare Engineering will play a role of growing importance in almost every aspect of healthcare, and will also be a major factor that advances healthcare. Healthcare Engineering professionals will face challenges associated with issues such as the continued rise in healthcare costs, the quality and safety of healthcare,

Table 2. Healthcare industry classification and contributions of Healthcare Engineering

Healthcare Industry			Contributions of Healthcare Engineering
Sector	Subsector	Definition	
Healthcare services, equipment, and systems	<i>Health care providers</i>	Health maintenance organizations, hospitals, clinics, dentists, allied health providers, opticians, nursing homes, rehabilitation facilities, retirement centers, and home healthcare providers.	Healthcare Engineering professionals play key roles in creating and developing hardware and software to innovate, support, improve and optimize the operation processes and systems of patient care, and to improve patient outcomes through engineering approaches.
	<i>Medical equipment</i>	Manufacturers and distributors of medical instruments (e.g., blood pressure monitor), medical devices (e.g., surgical robot), imaging machines (e.g., X-ray, MRI), artificial organs, and other non-disposable medical devices as well as medical software.	This is an area heavily relying on engineering expertise, and where Healthcare Engineering professionals make major contributions in basic research that leads to technology breakthroughs, as well as subsequent design, development, and manufacturing of medical devices and equipment.
	<i>Medical supplies</i>	Manufacturers and distributors of medical supplies used by health care providers and the general public, including makers of implants, contact lenses, eyeglass lenses, bandages and other disposable medical supplies.	Healthcare Engineering professionals contribute to the research & development of new products and manufacturing in terms of process design, machinery, automation, quality control, and cost reduction.

	<i>Healthcare systems</i>	Companies that specialize in healthcare systems including facilities, information, financial, and other systems.	Healthcare Engineering professionals work with healthcare providers to design, construct, improve, and/or operate healthcare facilities, information, financial, and other healthcare systems, following special regulations.
Pharmaceuticals and biotechnology	<i>Biotechnology</i>	Companies engaged in research into and development of biological substances leading to new drugs and/or medical procedures.	Healthcare Engineering professionals lead or participate in research and development of cutting-edge technologies for new drugs (including drug discovery, design, development, and delivery) and advanced medical procedures for the prevention, diagnosis, treatment, and management of illnesses.
	<i>Pharmaceuticals</i>	Manufacturers of prescription or over-the-counter drugs, such as aspirin, cold remedies and birth control pills, including vaccine producers.	Healthcare Engineering professionals contribute to the pharmaceutical manufacturing processes in terms of process design, unit operation, quality control, and cost reduction.
Healthcare consulting, support, and education		Companies that provide consulting service and support to healthcare, as well as continued education to healthcare personnel.	Healthcare Engineering professionals provide consulting service, support, and education on all aspects of healthcare involving engineering, such as optimizing healthcare operations, solving problems, providing informatics service, as well as designing, planning and/or executing new projects.

care of the aging population, management of common diseases, the impact of high technology, increasing demands for regulatory compliance, risk management, and reducing litigation risk. They will play a key role in creating, developing, and implementing cutting-edge devices and systems attributed to advances in electronics, information technology, miniaturization, material science, optics, and other fields. As technology continues to create new areas for engineers to work in healthcare, and the fusion of engineering with health sciences leads to a greater demand for engineers, Healthcare Engineering will be recognized as the most important profession where engineers make major contributions directly benefiting human health.

4. CONCLUDING REMARKS

In presenting a definition of Healthcare Engineering as an academic discipline, an area of research, a field of specialty, and a profession, we expect this document to have impacts in terms of the following:

- Raising the status and visibility of Healthcare Engineering.
- Helping students choose Healthcare Engineering-related fields as majors.
- Helping engineers and healthcare professionals choose Healthcare Engineering as a profession.
- Defining Healthcare Engineering as a specialty area for the research community, funding agencies, and conference/event organizers.
- Helping job searching databases properly categorize Healthcare Engineering jobs.
- Helping healthcare employers recruit from the right pool of expertise.
- Bringing academic administrators' attention to Healthcare Engineering in considering new program initiations.
- Helping governments and institutions of different levels put Healthcare Engineering into perspective for policy making, budgeting, and other purposes.
- Helping publishers and librarians categorize literature related to Healthcare Engineering.

It is our humble belief that this document will serve as a cornerstone for the development of Healthcare Engineering in decades to come.

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CONFLICT OF INTEREST

The authors indicated no potential conflicts of interest.

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